The Chemical Evaluation of a Continuous-Smoking Inhalation Machine*

by

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INTRODUCTION

The previous paper (1) described a design of inhalation smoking machine which is intended to present diluted smoke to 72 animals with a minimum delay.

The object of the present paper is to evaluate the machine in terms of smoke delivery, to compare the delivery with that of a reference analytical machine, and to account for any difference in delivery between machines. An appreciation of inhalation machine performance and its effects on smoke chemistry is necessary for the interpretation of biological results from animal exposures using this machine.

The paper will describe the methods and results obtained from an evaluation of the inhalation smoking machine in terms of PMWNF⁺, nicotine, carbon monoxide (CO) and other smoke chemicals at various points in the machine

(at the smoke pump, at the dilution chamber and at the animal ports), and will compare results with reference analytical data. Attempts will be made to account for any differences between the two machines, using a range of cigarette types at dilutions similar to those used in biological experiments.

METHODS AND MATERIALS

1. Cigarettes

The cigarettes used in this study are described in Table 1. Before smoking, the cigarettes were conditioned for at least 48 hours at 60% relative humidity and 21 °C, and were smoked under standard conditions, i.e. 35 ml puff of 2 seconds duration, once per minute to a butt length of overwrap plus 3 mm (2). The cigarettes were not weight or pressure drop selected for this work.

Table 1. Cigarettes used in this study.

	Length (mm)			Paper type	Filter type	Circumference (mm)	Weight (mg)	Pressure drop*** in daPa	Pressure drop*** in mm H ₂ O
	overall	filler	filter						
100% tobacco	72	56	16	low porosity	dual, acetate/myria	25.1	796	115	117
50% tobacco : 50% Cytrel®	72	56	16	low porosity	dual, acetate/myria	25.1	765	98	100
100% Cytrel®	72	56	16	low porosity	dual, acetate/myria	25.1	782	97	99
50% tobacco : 50% NSM 14**	72	56	16	low porosity	dual, acetate/myria	25.1	771	105	107
100% NSM 14	72	56	16	low porosity	dual, acetate/myria	25.1	782	96	98
100% tobacco, ventilated	72	55	17	medium porosity	dual, acetate/myria-carbon (ventilated)	25.1	760	127	130

* Cytrel® is a registered trade mark of Celanese Corporation.

Type 361 (Lot 227) was the specific variant used in these studies.

** NSM is a trade mark of New Smoking Materials Ltd., Fulshaw Hall, P.O. Box 3, Wilmslow, Cheshire, England.

*** 1 mm water = 0.980 daPa.

Figure 1. Schematic layout of Inhalation machine.

Table 2. Comparison for various cigarettes of undiluted smoke deliveries from Inhalation machine with analytical data.

Cigarette	Smoking machine	PMWNF* (mg/cigarette)	Nicotine (mg/cigarette)	CO (mg/cigarette)	Puff number
100 % tobacco	Inhalation	16.3 ± 0.2	1.18 ± 0.03	16.2 ± 0.3	9.1 ± 0.2
	Analytical	19.7 ± 0.9	1.35 ± 0.03	17.2 ± 0.7	10.2 ± 0.3
	Ratio inhalation : analytical	0.83 ± 0.03	0.87 ± 0.02	0.94 ± 0.03	0.89 ± 0.02
50 % tobacco : 50 % Cytrel	Inhalation	8.5 ± 0.9	0.32 ± 0.03	10.9 ± 0.5	6.2 ± 0.1
	Analytical	10.9 ± 0.3	0.51 ± 0.02	12.5 ± 0.6	7.1 ± 0.1
	Ratio inhalation : analytical	0.78 ± 0.07	0.63 ± 0.05	0.88 ± 0.04	0.87 ± 0.01
100 % Cytrel	Inhalation	3.1 ± 0.1	0	4.5 ± 0.1	5.0 ± 0.0
	Analytical	4.1 ± 0.2	0	5.4 ± 0.2	5.6 ± 0.1
	Ratio inhalation : analytical	0.76 ± 0.03	—	0.85 ± 0.02	0.89 ± 0.01
50 % tobacco : 50 % NSM 14	Inhalation	10.2 ± 0.7	0.39 ± 0.02	13.4 ± 0.3	8.1 ± 0.2
	Analytical	12.7 ± 0.4	0.56 ± 0.02	15.8 ± 0.9	9.2 ± 0.1
	Ratio inhalation : analytical	0.80 ± 0.05	0.70 ± 0.03	0.85 ± 0.04	0.88 ± 0.02
100 % NSM 14	Inhalation	3.8 ± 0.5	0	11.5 ± 0.4	9.3 ± 0.4
	Analytical	5.6 ± 0.6	0	11.4 ± 1.2	9.9 ± 0.4
	Ratio inhalation : analytical	0.68 ± 0.09	—	1.02 ± 0.08	0.94 ± 0.04
100 % tobacco, ventilated	Inhalation	8.1 ± 0.8	0.49 ± 0.03	10.0 ± 0.5	8.4 ± 0.1
	Analytical	9.2 ± 0.4	0.70 ± 0.10	11.5 ± 1.0	9.3 ± 0.2
	Ratio inhalation : analytical	0.88 ± 0.07	0.72 ± 0.08	0.88 ± 0.06	0.90 ± 0.02

* Particulate matter, water and nicotine free.

2. Analytical Smoke Chemistry

PMWNF, nicotine and CO were analysed using a Filtrona 300 twenty-channel piston smoking machine fitted with an automated CO collection and analysis unit (ATCOM 20) (3). Wet particulate matter (PM) was determined gravimetrically, nicotine by a steam distillation and spectrophotometric procedure, and water by gas chromatography (2). Carbon monoxide, after collection of vapour phase in the plastic bags of the ATCOM 20, was analysed by a non-dispersive infrared (NDIR) technique (2).

Hydrogen cyanide, total volatile aldehydes and steam volatile phenols were analysed using a 6-channel constant flow smoking machine using procedures described in (2). Formaldehyde was analysed on the same machine using a spectrophotometric procedure described by *Spencer and Chard* (4).

3. Inhalation Machine Smoke Chemistry

The details of the inhalation smoking machine are described elsewhere (1). The inhalation smoking machine was allowed to run for 2 hours prior to any experimentation; previous tests had established that puff volume was constant both with and without cigarettes after this initial warm up period. To sample and collect smoke immediately behind the pump (i.e. undiluted smoke), the dilution chamber was disconnected from the pump and the smoke was diverted into the appropriate trapping system for the analysis under consideration. Traps and analytical procedures were similar to those used in the analytical smoking procedures. Puffs of smoke taken into the traps were equivalent to those used in the analytical procedures; puff numbers on the turntable were randomized to eliminate any possibility of biased data. Flow rates were monitored throughout the analyses using rotameters calibrated against a wet gas meter.

Sampling of the diluted smoke at the distribution head and the upper, middle and lower animal levels was achieved by connecting a vacuum pump via a T piece at the appropriate position and pumping from these points through the appropriate trapping system. Diluted smoke was sampled over a 30-minute period; procedures were similar to those used in the analytical smoking.

In all cases, for analytical and inhalation smoking at each sampling point, at least 5 analyses were performed and results quoted are the means of these individual analyses. In the tables of results means and associated 95 % confidence limits are given, unless otherwise stated. In comparisons of inhalation and analytical smoking machine data, the 95 % confidence limit of the yield ratio inhalation : analytical machine is given by the equations:

$$\begin{aligned} \text{variance of the ratio } \left(\frac{\bar{x}_1}{\bar{x}_2} \right) &= \\ &= \left\{ \text{variance } (\bar{x}_1) + \left(\frac{\bar{x}_1}{\bar{x}_2} \right)^2 \cdot \text{variance } (\bar{x}_2) \right\} \frac{1}{(\bar{x}_2)^2} \end{aligned}$$

and

$$\begin{aligned} 95\% \text{ confidence limit of ratio } \left(\frac{\bar{x}_1}{\bar{x}_2} \right) &= \\ &= t \cdot \sqrt{\text{variance } \left(\frac{\bar{x}_1}{\bar{x}_2} \right)}, \end{aligned}$$

where

$\bar{x}_1$ is the mean inhalation machine smoke yield,
 $\bar{x}_2$ is the mean analytical machine smoke yield,
 t is the value from Student's t tables.

4. Estimation of Deposition

One of the main differences between the inhalation and analytical smoking machines is that in the former the pump is situated between the cigarettes and the trapping system (for sampling undiluted smoke). Deposition of smoke in the pump (or in the pipework behind the pump if sampling diluted smoke) is a possibility and so a method was developed to estimate this deposition level using non-volatile whole smoke condensate (NVWSC) (2). Starting with a clean machine (i.e. all pipework washed out with acetone) smoking was carried out in the usual manner, collecting the PM on a Cambridge filter pad at the appropriate sampling point. After smoking the specified number of cigarettes, the pump and pipework were washed with acetone and an aliquot was quantitatively assayed for nicotine. The remainder was rotary evaporated to constant weight at 40 °C and 133 daPa (10 mm Hg) to give a quantitative NVWSC yield (2). From correlations between NVWSC and PMWNF previously established for each product on test, the PMWNF equivalent deposited in the inhalation machine could be calculated. For example, for a 100 % tobacco cigarette PMWNF was 19.7 mg/cigarette and NVWSC 15.7 mg/cigarette, giving a relationship of PMWNF (mg/cigarette) = NVWSC (mg/cigarette) $\times$ 1.255. The deposition calculated in this way can be added to that collected on the pad in order to estimate the total PMWNF or nicotine delivery by the cigarette.

RESULTS AND DISCUSSION

I. Comparison of Undiluted Smoke Delivery with Analytical Data

1. PMWNF, Nicotine, CO

The delivery of smoke immediately behind the pump, i.e. position 1 (Figure 1), was compared to that delivered by a Filtrona 300 analytical smoking machine. Table 2 summarises data for a series of cigarette model products and shows that the inhalation machine consistently delivered less smoke than the analytical machine, although deliveries of CO were not so greatly reduced as were those of PMWNF and nicotine. Puff numbers were also consistently lower in the inhalation machine.

To try to explain the differences between the observed smoke deliveries from the two machines, the following

Table 3. Comparison of analytical and Inhalation machine undiluted smoke deliveries after correction for deposition and puff number.

Sample	Smoking machine	PMWNF* on pad (mg/cig.)	PMWNF deposited (mg/cig.)	PMWNF total (mg/cig.)	PMWNF** per puff (mg/puff)	Nicotine on pad (mg/cig.)	Nicotine deposited (mg/cig.)	Nicotine total (mg/cig.)	Nicotine** per puff (mg/puff)	CO (mg/cig.)	CO** per puff (mg/puff)
100% tobacco	Inhalation	16.0 ± 0.5	1.65 ± 0.54	17.7 ± 0.3	1.95 ± 0.03	1.18 ± 0.08	0.08 ± 0	1.26 ± 0.08	0.14 ± 0.02	16.2 ± 1.1	1.78 ± 0.12
	Analytical	19.7 ± 0.9	—	—	2.03 ± 0.09	1.35 ± 0.03	—	—	0.14 ± 0.02	17.2 ± 0.7	1.77 ± 0.07
	Ratio inhalation : analytical	0.82 ± 0.03	—	0.90 ± 0.03	0.97 ± 0.03	0.87 ± 0.02	—	0.92 ± 0.02	1.00 ± 0.15	0.94 ± 0.03	1.01 ± 0.05
50% tobacco : 50% Cytrel	Inhalation	8.4 ± 0.9	0.78 ± 0.20	9.2 ± 0.9	1.48 ± 0.09	0.32 ± 0.03	0.05 ± 0	0.37 ± 0.03	0.06 ± 0.01	10.9 ± 0.5	1.76 ± 0.02
	Analytical	10.9 ± 0.3	—	—	1.53 ± 0.03	0.51 ± 0.02	—	—	0.07 ± 0.01	12.5 ± 0.6	1.76 ± 0.02
	Ratio inhalation : analytical	0.78 ± 0.07	—	0.85 ± 0.07	0.97 ± 0.05	0.63 ± 0.05	—	0.73 ± 0.05	0.86 ± 0.14	0.88 ± 0.04	1.00 ± 0.01
100% Cytrel	Inhalation	3.3 ± 0.1	0.34 ± 0.16	3.6 ± 0.2	0.72 ± 0.04	0	0	0	0	4.5 ± 0.1	0.91 ± 0.02
	Analytical	4.1 ± 0.2	—	—	0.73 ± 0.04	0	—	—	0	5.4 ± 0.2	0.96 ± 0.04
	Ratio inhalation : analytical	0.76 ± 0.03	—	0.88 ± 0.03	0.99 ± 0.06	—	—	—	—	0.85 ± 0.02	0.95 ± 0.03

* Particulate matter, water and nicotine free.

** Using puff No. data given in Table 2.

possibilities were investigated (bearing in mind that puff volume, cigarette conditioning, puff duration, puff interval and butt length were identical in the two machines):

a) *Deposition of PM inside the pump*: This can happen in the inhalation machine as the pump is sited between the cigarettes and the Cambridge filter pad. The observation that CO differences between the two machines were small compared to PMWNF and nicotine differences suggests that particulates could be deposited inside the pump. To evaluate this, the pump and pathway were washed with acetone after smoking and NVWSC yield (and nicotine) measured on the washings as described previously. Such determinations were made on a range of products and data are summarised in Table 3, in which corrected yields are given after allowance for deposition. If the data from inhalation and analytical machines are then corrected for the difference in puff number, by quoting an average yield per puff, analytical and inhalation data compare quite favourably.

b) *Free burning time*: In the inhalation machine, cigarettes are on a rotating turntable whereas in the analytical machine they are stationary, possibly introducing differences in free burning. Although a given cigarette gave identical free burning times without puffing on both machines, differences were observed when a puffing cycle was introduced. Figure 2 illustrates the differences between inter-puff free burning and puffing paper regressions for the two machines. The inhalation machine gave much greater regressions between puffs, and slightly greater regressions during puffs, than the analytical machine using a 100 % tobacco cigarette. The difference in inter-puff free burning could account for the observed puff number difference between the two machines, possibly through a difference in cone shapes immediately after puffing in the two different profiles (bell-shaped v. square wave).

c) *Restricted v. unrestricted smoking**: The analytical smoking machine uses restricted smoking, the inhalation machine unrestricted. This could account for the differences in PM delivery in addition to the paper regressions discussed above. Using a comparable rotary turntable which gave restricted smoking, it was possible to compare smoke

Table 4. Comparison of restricted and unrestricted smoking using 100 % tobacco cigarettes on rotary machinery.

Smoking machine	PMWNF* (mg/cigarette)	Nicotine (mg/cigarette)	Puff number
Restricted	19.2 ± 1.0	1.36 ± 0.08	9.6 ± 0.4
Unrestricted	18.7 ± 0.9	1.29 ± 0.05	9.2 ± 0.3

* Particulate matter, water and nicotine free.

deliveries directly with the inhalation machine. Results (Table 4) indicate that the style of smoking does not contribute to the observed differences in smoke delivery for the products used in this study.

* Restricted and unrestricted smoking are, respectively, the conditions that exist when the butt end of the cigarette is closed and open to the atmosphere between successive puffs.

Figure 2. Comparison of paper regressions during puffing and during the inter-puff free burning interval for the Inhalation and analytical smoking machines (100 % tobacco cigarette).

Analytical smoking machine:

average regression of paper during puffs = 3.6 mm

average regression of paper between puffs = 1.3 mm

Inhalation smoking machine:

average regression of paper during puffs = 3.9 mm

average regression of paper between puffs = 1.9 mm

d) *Puff profile effects*: The analytical machine has a bell-shaped profile whereas the inhalation machine has a square wave. It was not possible to investigate the effect of this parameter: *Seehofer and Schulz* (5) claimed that no differences were observed on filter cigarettes for these two puff profiles.

e) *Effect of neighbouring cigarettes during smoking*: On the inhalation machine, the axes of two adjacent cigarettes on the turntable are 23–33 mm apart, as opposed to the analytical machine, where they are 65 mm apart. Each cigarette on the inhalation machine could heat its neighbours by irradiation. To clarify the effect of this, the PMWNF, nicotine and CO yields were recorded for thirty 100 % tobacco cigarettes smoked in rotation, 5 cigarettes smoked in rotation on adjacent ports and 5 cigarettes smoked consecutively in one single port, on the inhalation smoker. Results (Table 5) show that any irradiation effects, if present, do not adversely affect smoke yields.

f) *Cigarette lighting*: The inhalation machine uses flame ignition, whereas the analytical machine uses electrical ignition. The lighting puff regression was identical in both

Table 8. Inhalation machine balance sheet compared to analytical machine for various cigarettes on a per puff basis.

Sample	Smoking machine and sampling position	Smoke concentration (% (v/v))	PMWNF* on pad ($\mu\text{g/puff}$)	PMWNF deposited ($\mu\text{g/puff}$)	PMWNF total ($\mu\text{g/puff}$)	Nicotine on pad ($\mu\text{g/puff}$)	Nicotine deposited ($\mu\text{g/puff}$)	Nicotine total ($\mu\text{g/puff}$)	CO ($\mu\text{g/puff}$)
100% tobacco		1.45 $\pm$ 0.02							
	Inhalation — position 1		1926 $\pm$ 179	106 $\pm$ 49	2032 $\pm$ 186	147 $\pm$ 5	4 $\pm$ 1	151 $\pm$ 5	1748 $\pm$ 59
	— position 2		1588 $\pm$ 143	203 $\pm$ 62	1791 $\pm$ 156	123 $\pm$ 8	7 $\pm$ 1	130 $\pm$ 8	1548 $\pm$ 59
	— position 3		1507 $\pm$ 123	n.d.**	n.d.	127 $\pm$ 4	n.d.	n.d.	n.d.
	Analytical		2095 $\pm$ 96	—	—	149 $\pm$ 9	—	—	1876 $\pm$ 206
50% tobacco : 50% Cytrel		2.01 $\pm$ 0.01							
	Inhalation — position 1		1202 $\pm$ 89	94 $\pm$ 39	1296 $\pm$ 97	81 $\pm$ 4	2 $\pm$ 1	83 $\pm$ 4	1620 $\pm$ 84
	— position 2		996 $\pm$ 125	190 $\pm$ 64	1186 $\pm$ 140	61 $\pm$ 10	3 $\pm$ 1	64 $\pm$ 10	1644 $\pm$ 90
	— position 3		925 $\pm$ 59	n.d.	n.d.	64 $\pm$ 6	n.d.	n.d.	n.d.
	Analytical		1466 $\pm$ 33	—	—	82 $\pm$ 5	—	—	1748 $\pm$ 80
100% Cytrel		5.54 $\pm$ 0.06							
	Inhalation — position 1		515 $\pm$ 78	48 $\pm$ 4	563 $\pm$ 78	0	0	0	1092 $\pm$ 24
	— position 2		449 $\pm$ 30	87 $\pm$ 61	536 $\pm$ 68	0	0	0	1007 $\pm$ 58
	— position 3		440 $\pm$ 79	n.d.	n.d.	0	0	0	n.d.
	Analytical		557 $\pm$ 141	—	—	—	—	—	1105 $\pm$ 85

* Particulate matter, water and nicotine free.

** n.d. = not determined.

Table 5. The effect of neighbouring cigarettes on each other during smoking — Inhalation machine (100 % tobacco cigarettes).

Experiment	PMWNF* (mg/cig.)	Nicotine (mg/cig.)	CO (mg/cig.)	Puff number
30 cigarettes in rotation	15.3	1.12	16.0	9.0
5 cigarettes in rotation (adjacent ports)	15.7	1.14	16.2	9.0
5 cigarettes on a single port	15.1	1.12	15.9	9.0

* Particulate matter, water and nicotine free.

machines, and was generally thought unlikely to contribute to the observed differences.

It would appear, therefore, that the losses incurred at the sampling position 1, immediately behind the pump, are due to two main causes: (a) deposition within the pump and (b) differences in puff number.

2. Other Smoke Chemicals

Having determined smoke quantity at sampling position 1 and smoke quality using CO and nicotine, it was decided to compare deliveries of certain key chemicals in the smoke. Thus hydrogen cyanide, total volatile aldehydes, steam volatile phenols and formaldehyde were measured in the undiluted smoke. Results (Table 6) suggest that there is little difference between the two smoking machines in the delivery of these chemicals.

II. Comparison of Diluted Smoke Delivery with Analytical Data

For this aspect of the work, four sampling positions were available (Figure 1): at the top of the animal trays (position 2), and at each of the three trays (positions 3, 4, 5). A preliminary investigation using a 50 % tobacco : 50 % Cytrel cigarette at a smoke concentration of 2.0 % (v/v) was undertaken to establish if any differences existed between the three animal tray levels. Results (Table 7)

Table 7. Comparison of smoke delivery data at the three animal port levels (positions 3, 4, 5) from 50 % tobacco : 50 % Cytrel cigarette at 2 % (v/v) smoke concentration.

	Position 3 (upper level)	Position 4 (middle level)	Position 5 (lower level)
PMWNF* (µg/puff)	924 ± 142	933 ± 146	919 ± 125
Nicotine (µg/puff)	64 ± 12	64 ± 33	64 ± 14

* Particulate matter, water and nicotine free.

show that there were no statistically significant differences between the three levels.

Positions 1, 2, 3 were sampled using three cigarette types at smoke concentrations typical of those used in animal inhalation experiments. In addition to measuring PMWNF, nicotine and CO at the three positions, deposition was measured up to positions 1 and 2. Recognising that puff number is a major difference between the inhalation and analytical machines, all data are expressed as average yields per puff. Actual deliveries and comparisons with analytical machine data are given in Table 8; ratios of inhalation and analytical machine data are shown in Table 9.

In actual deliveries on a per puff basis, the inhalation machine delivers slightly less smoke to position 1 than the analytical data would indicate, the difference being wholly accountable for by deposition. There are further losses in actual delivery to position 2 and again to position 3, particularly in PMWNF, as indicated in Table 8, and after accounting for deposition there still appear to be losses. Carbon monoxide deliveries are slightly lower at positions 2 and 3 and these could suggest some evidence of leakage. For example, the total recoveries for PMWNF, nicotine and CO for the 100 % tobacco product at position 2 are about 85 %. There is also evidence of PMWNF's selectively depositing (11 %—16 %) compared to nicotine (5 %), indicating that nicotine may be transferred in part to the vapour phase.

Some studies were made on hydrogen cyanide and total volatile aldehyde deliveries to the 1st level of the animal trays — position 3 — using 100 % tobacco cigarettes at 1.45 % (v/v) smoke concentration. Table 10 indicates an average recovery of 85 % of these chemicals when calcu-

Table 6. Comparison of smoke chemistry: undiluted smoke from Inhalation machine v. analytical machine.

Samples	Smoking machine	HCN (µg/cigarette)	Aldehydes (mg/cigarette)	Formaldehyde (µg/cigarette)	Phenols (µg/cigarette)
100 % tobacco	Inhalation	297 ± 14	1.9 ± 0.1	82 ± 2	87 ± 3
	Analytical	330 ± 14	2.5 ± 0.1	77 ± 3	90 ± 2
	Ratio inhalation : analytical	0.90 ± 0.06	0.76 ± 0.04	1.06 ± 0.04	0.97 ± 0.04
50 % tobacco : 50 % Cytrel	Inhalation	136 ± 12	1.2 ± 0.1	62 ± 5	33 ± 3
	Analytical	144 ± 11	1.3 ± 0.1	53 ± 3	32 ± 7
	Ratio inhalation : analytical	0.94 ± 0.10	0.92 ± 0.11	1.13 ± 0.11	1.03 ± 0.07
100 % Cytrel	Inhalation	7 ± 1	0.2 ± 0.1	10 ± 3	15 ± 4
	Analytical	5 ± 1	0.5 ± 0.1	12 ± 1	17 ± 3
	Ratio inhalation : analytical	1.40 ± 0.30	0.40 ± 0.05	0.83 ± 0.25	0.88 ± 0.25

Table 9. Ratio of Inhalation machine yields compared to analytical machine for various cigarettes on a per puff basis.

Sample	Smoking machine and sampling position	Smoke concentration (% (v/v))	PMWNF* on pad	PMWNF** total	Nicotine on pad	Nicotine total	CO
100 % tobacco		1.45 ± 0.02					
	Inhalation (position 1) : analytical		0.92 ± 0.07	0.97 ± 0.07	0.99 ± 0.05	1.01 ± 0.05	0.93 ± 0.08
	Inhalation (position 2) : analytical		0.76 ± 0.06	0.85 ± 0.06	0.83 ± 0.06	0.87 ± 0.06	0.83 ± 0.07
	Inhalation (position 3) : analytical		0.72 ± 0.05	—	0.85 ± 0.04	—	—
50 % tobacco : 50 % Cytrel		2.01 ± 0.01					
	Inhalation (position 1) : analytical		0.82 ± 0.05	0.88 ± 0.05	0.99 ± 0.06	1.01 ± 0.06	0.93 ± 0.05
	Inhalation (position 2) : analytical		0.68 ± 0.06	0.81 ± 0.06	0.74 ± 0.09	0.78 ± 0.09	0.94 ± 0.05
	Inhalation (position 3) : analytical		0.63 ± 0.04	—	0.78 ± 0.08	—	—
100 % Cytrel		5.54 ± 0.06					
	Inhalation (position 1) : analytical		0.92 ± 0.20	1.01 ± 0.20	—	—	0.99 ± 0.06
	Inhalation (position 2) : analytical		0.81 ± 0.15	0.96 ± 0.15	—	—	0.91 ± 0.06
	Inhalation (position 3) : analytical		0.79 ± 0.18	—	—	—	—

* Particulate matter, water and nicotine free.

** PMWNF total is the sum of the PMWNF on the pad and that deposited in the machine.

Table 11. Effect of smoke concentration on inhalation machine actual smoke delivery.

Sample	Smoking machine	Smoke concentration (% (v/v))	PMWNF* (µg/puff)	Nicotine (µg/puff)	CO (µg/puff)
100 % tobacco	Inhalation machine (position 3)	1.45	1507 ± 123	127 ± 4	1548 ± 59
		1.75	1330 ± 76	120 ± 2	1490 ± 36
		2.00	1330 ± 63	124 ± 2	1500 ± 59
		3.00	1320 ± 13	123 ± 1	1470 ± 44
	Analytical machine	—	2095 ± 96	149 ± 9	1876 ± 206
	Ratio inhalation (mean) : analytical	—	0.65	0.83	0.80
50 % tobacco : 50 % Cytrel	Inhalation machine (position 3)	2.01	925 ± 59	64 ± 6	1644 ± 90
		2.25	939 ± 100	61 ± 5	1420 ± 36
		3.00	974 ± 72	61 ± 6	1420 ± 23
		4.00	990 ± 28	71 ± 2	1365 ± 36
	Analytical machine	—	1466 ± 33	82 ± 5	1748 ± 80
	Ratio inhalation (mean) : analytical	—	0.65	0.78	0.84

* Particulate matter, water and nicotine free.

Table 10. Inhalation machine: diluted smoke chemistry* for 100 % tobacco cigarettes at 1.45 % (v/v) smoke concentration (sampling at animal tray position 3).

Machine	HCN ($\mu\text{g/puff}$)	Aldehydes ($\mu\text{g/puff}$)
Inhalation machine (position 3)	27.1 max. = 29.6 min. = 25.1	220 max. = 238 min. = 203
Analytical machine	32.8 max. = 35.1 min. = 30.2	257 max. = 260 min. = 250
Ratio inhalation: analytical	0.83 max. = 0.84 min. = 0.81	0.86 max. = 0.91 min. = 0.78

* Three determinations per quoted mean result.

lated on a per puff basis, and as such compare favourably with the CO data (Table 9).

To see if smoke concentration has any effect on actual smoke delivery from the inhalation machine, two cigarette types were studied over a range of smoke concentrations, keeping within the range normally encountered in animal exposure experiments. Data for these two products [100 % tobacco over the range 1.45 %–3.0 % (v/v) and 50 % tobacco : 50 % Cytrel over the range 2.0 %–4.0 % (v/v)] are given in Table 11, data on the diluted smoke being obtained at the 1st level of animal trays. It is clear that dilution has no significant effect on smoke delivery; the data also confirm the observation in Table 8 that PMWNF actually delivered from the inhalation machine is less than the delivery of nicotine and CO.

SUMMARY

The paper describes experiments which have been used to evaluate an inhalation smoking machine for small animals. Deliveries of undiluted and diluted smoke from this machine have been compared to reference data obtained from an analytical smoking machine. Deliveries of smoke immediately behind the smoke pump were lower than those from the analytical machine, largely due to differences in puff number (created largely by differences in paper regression between puffs) and deposition. When these factors were accounted for, deliveries from the two machines compared favourably. However, deliveries of diluted smoke, although apparently independent of dilution level, were somewhat lower than analytical deliveries. Thus the inhalation machine delivered about 65 % of the particulate matter, 80 % of the nicotine and 85 % of the carbon monoxide delivered by the analytical machine on a per puff basis (for 100 % tobacco or 50 % tobacco : 50 % Cytrel). A 100 % Cytrel cigarette delivered 80 % of the particulate matter and 90 % of the carbon monoxide (no nicotine). After accounting for deposition, consistent deliveries of about 85 % were achieved for all three constituents in all-tobacco cigarettes, while corrected deliveries for 100 % Cytrel cigarettes were about 90 % for both particulate matter and carbon monoxide. Deliveries of hydrogen cyanide and total volatile aldehydes in both samples were about 85 % of those achieved on an analytical machine.

ZUSAMMENFASSUNG

Zum Zweck der Beurteilung einer Inhalationsrauchmaschine für kleine Labortiere wurden Versuche durchgeführt. Die von der Maschine erzeugten Mengen an unverdünntem und verdünntem Rauch wurden mit den entsprechenden Daten einer analytischen Rauchmaschine verglichen. Die unmittelbar hinter der Raumpumpe gemessenen Rauchmengen waren bei der Inhalationsrauchmaschine niedriger als bei der analytischen Rauchmaschine, was hauptsächlich auf Rauchniederschlag im Rohrsystem und auf Unterschiede in der Zugzahl (vor allem durch unterschiedlichen Abbrand im Zugintervall) zurückgeführt wird. Unter Berücksichtigung dieser beiden Faktoren waren die von den beiden Rauchmaschinen erzeugten Rauchmengen vergleichbar. Trotzdem lag die Ausbeute der Inhalationsrauchmaschine bei verdünntem Rauch etwas unter derjenigen der analytischen Maschine, und zwar unabhängig vom Verdünnungsgrad. So betrugen die Ausbeuten der Inhalationsrauchmaschine im Vergleich zur analytischen Rauchmaschine auf Zugbasis bei der Partikelmasse (PMWNF*) etwa 65 %, beim Nikotin 80 % und beim Kohlenmonoxid 85 % (100 % Tabak oder Tabak/Cytrel® im Verhältnis 50:50). Bei einer zu 100 % aus Cytrel® bestehenden Zigarette beliefen sich diese Werte auf 80 % für die Partikelmasse und auf 90 % für das Kohlenmonoxid (kein Nikotin). Unter Berücksichtigung der Rauchablagerung machten die Ausbeuten an den drei Komponenten bei zu 100 % aus Tabak bestehenden Zigaretten regelmäßig etwa 85 % aus, während sich die korrigierten Ausbeuten bei Cytrel®-Zigaretten (100 %) auf etwa 90 % sowohl für die Partikelmasse wie für das Kohlenmonoxid beliefen. Bei beiden Proben machten die Ausbeuten der Inhalationsrauchmaschine an Blausäure (HCN) und gesamten flüchtigen Aldehyden etwa 85 % der Ausbeuten der analytischen Rauchmaschine aus.

RÉSUMÉ

Cette étude décrit les expériences effectuées pour évaluer une machine à fumer servant à exposer de petits animaux à la fumée de cigarette par voie d'inhalation. Les quantités de fumée diluée et non diluée délivrées par cette machine sont comparées à des données de référence obtenues par une machine à fumer analytique. La quantité de fumée mesurée directement derrière la pompe à fumer est plus basse que celle de la machine analytique, en raison surtout de différences dans le nombre de bouffées (attribuables principalement à la vitesse de combustion plus grande entre les bouffées) et d'un dépôt de particule dans la machine. En dehors de ces deux facteurs, les rendements en fumée des deux machines sont comparables. Cependant, le rendement en fumée diluée de la machine servant à l'inhalation, bien qu'apparemment indépendant du degré de dilution, est quelque peu inférieur à celui de la machine analytique. Ainsi, par rapport à la machine analytique, et pour un nombre égal de bouffées, la machine servant à

* particulate matter, water and nicotine free

l'inhalation produit environ 65 % de condensat anhydre sans nicotine (PMWNF*), 80 % de nicotine et 85 % de CO (avec du tabac 100 % ou un mélange à parts égales de tabac et de Cytrel®). Avec une cigarette contenant 100 % de Cytrel®, les valeurs de rendement sont de 80 % de condensat anhydre et de 90 % de CO (la nicotine est absente). En tenant compte du dépôt dans la machine, des rendements réguliers d'environ 85 % ont été obtenus pour ces trois constituants de la fumée pour les cigarettes faites de 100 % de tabac alors que les rendements corrigés pour les cigarettes composées de 100 % de Cytrel® sont d'environ 90 % aussi bien pour le condensat anhydre que pour le CO. Les rendements en acide cyanhydrique et en aldéhydes volatils totaux sont d'environ 85 % de ceux de la machine analytique pour les deux échantillons.

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